Coastal Mixing

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LONG-TERM GOALS

I seek to understand the mechanisms of turbulence and mixing in shallow water sufficiently well to be able to specify useful parameterizations for coastal circulation models. I seek to understand the links between mixing rates, the circulation and productivity of the coastal ocean. I seek to develop the technology to make accurate Lagrangian measurement of ocean processes and the analysis techniques to use it.

OBJECTIVES

The short-term objective is to analyze mixing and circulation measurements made in the Oregon upwelling system during the summers of 2000 and 2001.

APPROACH

Neutrally buoyant Lagrangian floats were deployed on the Oregon Shelf during the summers of 2000 and 2001. The float motion measures water parcel trajectories. High frequency measurements along the float trajectory is used to infer mixing dynamics. Our primary task in FY03 was to analyze these data.

The Lagrangian floats (see Fig. 1) are versions of Lagrangian float technology that we have been developing since about 1990. They are designed to accurately follow the three-dimensional motion of water parcels at the time scales of mixing and isopycnal surfaces on longer time scales. This is done by adjusting the float's buoyancy based on CTD measurements on the float. A large folding drogue increases the vertical drag. Sensors on the float measure the changes in water properties following the water. Measurements are made autonomously for up to several months. Operational data is relayed to shore and mission parameters controlled via two-way satellite telemetry. These transmissions are made during periodic surfacings of the float, which also provide profiles of upper ocean properties and GPS fixes. Scientific data, typically several hundred Mbytes, is stored internally and extracted after the float is recovered.

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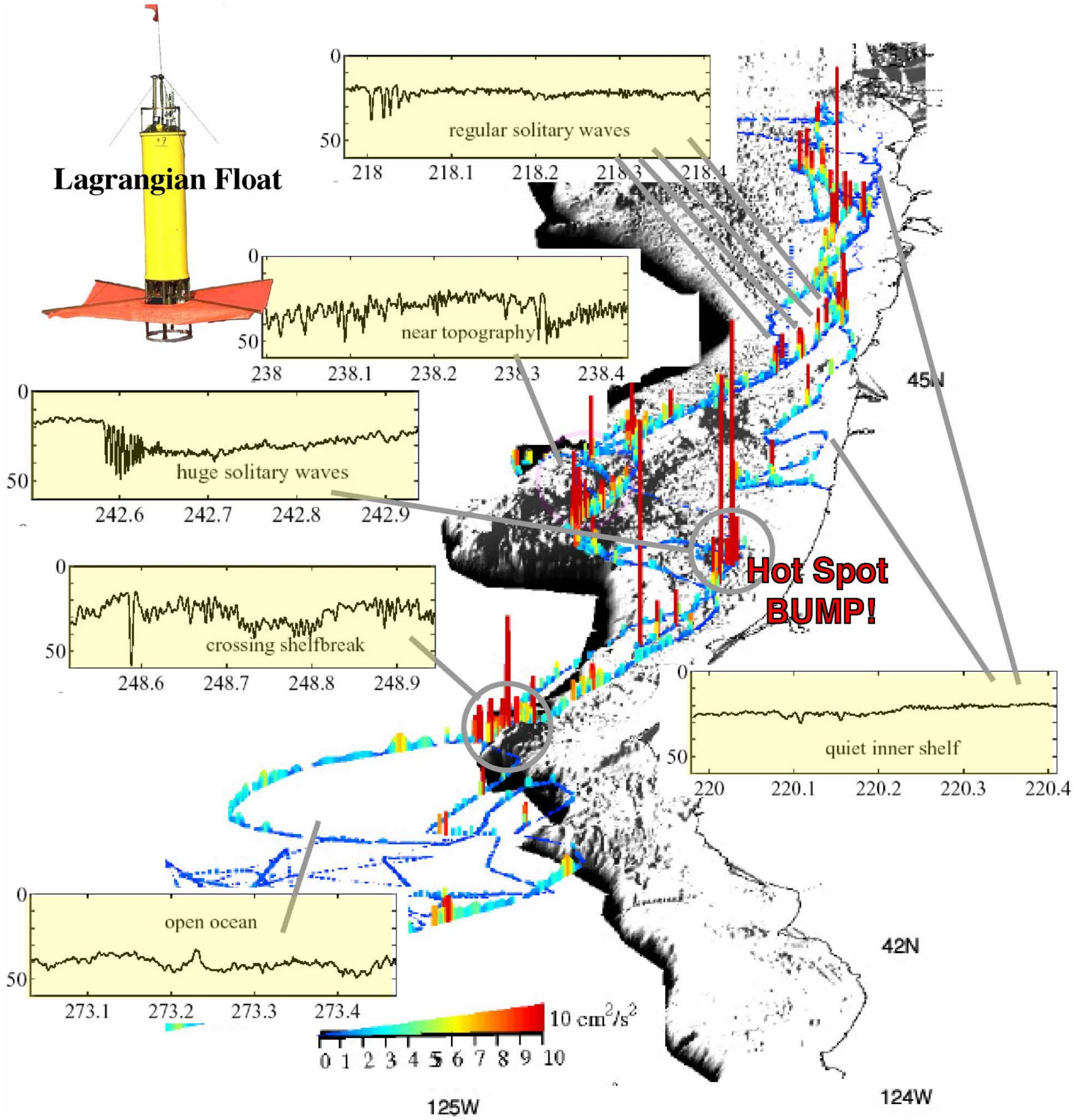

Figure 1. Left: Lagrangian float (upper left) consists of an approximately 1m long pressure hull with CTD and sonar sensors mounted on the endcaps, a folding cloth drogue in the middle and recovery equipment on the top. Floats were deployed on the northern part of the Oregon shelf, as shown in this figure, and were carried south by the prevailing current. Each colored line in the figure shows the track of one float. Colors and vertical bars along the track show 1-hr-average vertical kinetic energy computed from the float's vertical motion. Yellow boxes show 12-hr-long selected depth-time segments of float data from characteristic regions of the shelf.

These floats are designed to easily accommodate a variety of sensors. All measure pressure and carry at least one CTD, since these instruments are necessary to operate and ballast the float. Two auxiliary instrument suites were deployed in 2001. A ``mixing" float carried two CTD's, one on each end of the float, a high accuracy Doppler sonar which measured vector velocity near the top CTD and other experimental sensors. This enabled shear, strain and Richardson number

to be measured. A ``Biofloat" (funded internally by APL/UW) carried chlorophyll fluorescence and irradiance sensors.

WORK COMPLETED

Analysis completed during FY03 includes publication of a paper on the float technology (D'Asaro, Eric A. 2003), completion of the calibration and dealiasing of the high accuracy sonar on the mixing float, analysis of the distribution of internal wave energy on the shelf (see below) and analysis of the upwelling and circulation implications of the data. Some of these results are highlighted below.

RESULTS

High frequency internal wave distribution The vertical motion of Lagrangian floats yields highly accurate measaurements of vertical velocity. Fig. 1 shows the 1-hr-average vertical kinetic energy along each float track computed from the float data. These are an accurate measure of the energy in high frequency internal waves. Each panel shows a representative section of float data. We find:

- Internal wave energy is high over rough topography and near the shelf break.
- Internal wave energy is low in the open ocean and near the shore
- Between these, on mid shelf, packets of nonlinear internal waves (others might call them "solitary waves") are often found.
- This distribution is consistent with internal wave packets being generated on rough topography and near the shelf break and propagating both seaward and landward. A particularly potent source is identified as a small bump on the shelf labelled "Hot Spot" in the figure.
- Assuming shoreward propagation and a reasonable group velocity, the energy dissipated by these waves would result in a diapycnal diffusivity of about 10^{-5} m^2 s^{-1} comparable to the typical open ocean value. This is probably only a fraction of the total diffusivity on the shelf.

High frequency internal wave dynamics. Fig. 2., and its lengthy caption, describe an analysis of the dynamics of an internal wave packet observed by the "mixing" float. We find:

- Shear, stratification and thus mixing rates beneath the internal wave packet are controlled primarily by the nonlinear straining of the background low frequency shear and stratification through which the packet propagates. The measured shear is much larger than that which would be due to the wave alone.
- The wave packet therefore acts as a catalyst for mixing concentrating the existing shear and thereby reducing the Richardson number at the bottom of each wave and leading to mixing during the wave passage. This agrees well with more direct observations of mixing in these waves by Moum, Armi and Farmer.
- Mixing associated with the waves therefore is not a property of the wave alone but depends on both the wave and its environment. Energy for the mixing is drawn from both the wave energy and the much larger store of energy in the background shear field.

- This is consistent with the "solibore"; these waves are not isolated features but interact continually with the flow in which they are embedded.

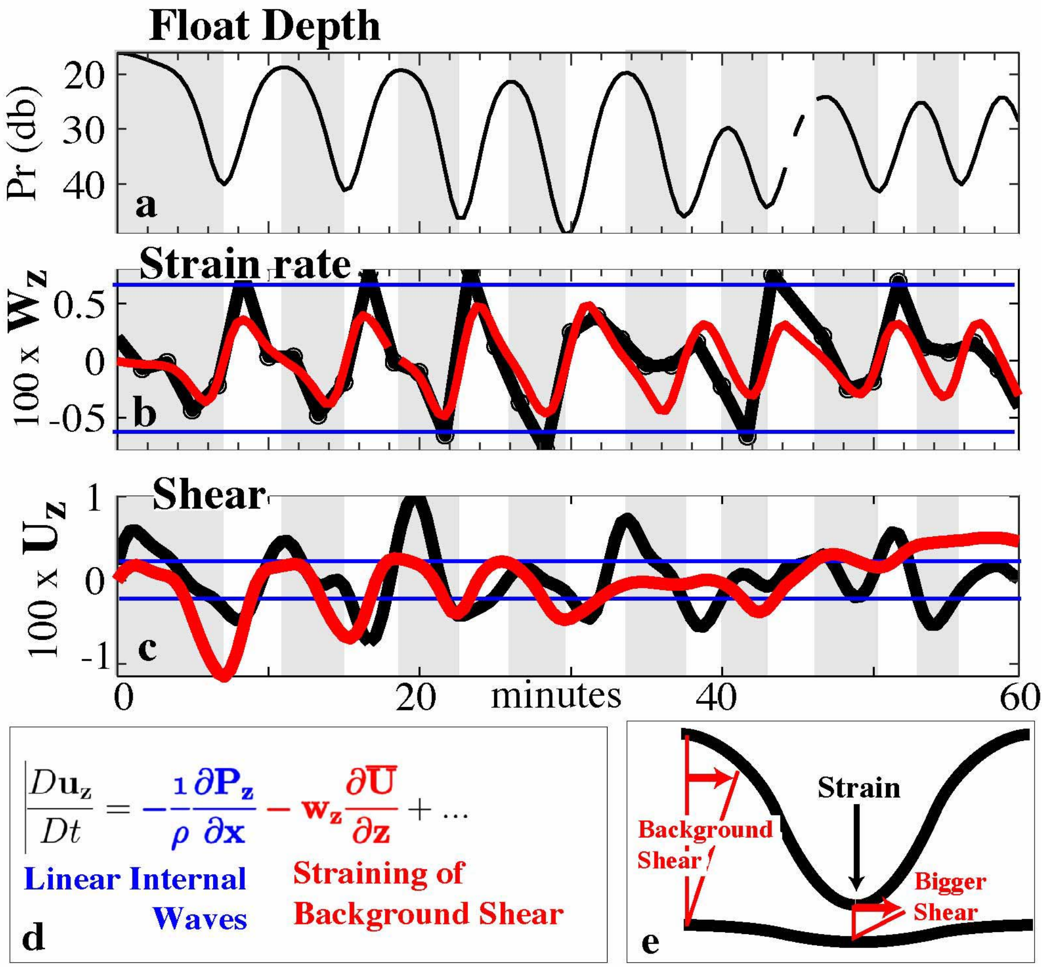

Figure 2. Dynamical analysis of an internal wave packet observed by a Lagrangian float on the Oregon shelf. a) Time series of float depth vrs time. The float undergoes repeated oscillations between 20 and 40 db depth as it is carried vertically by the wave. Density measurements on the float indicate that the float is remaining within a meter of the same isopycnal during this time. b) Strain rate (black), i.e. the 1 m vertical difference of vertical velocity as measured by a Doppler sonar on the float. This oscillates in phase with the float depth. c) Shear (black), i.e. the 1m vertical difference of horizontal velocity as measured by the Doppler sonar. It also varies with the float depth. d) Three terms in the equation for the rate of change of shear. The first right-hand term (in blue) is the one associated with linear internal wave dynamics. If this were the dominant term, then the strain and shear must be bounded by the blue horizontal lines in b) and c). The shear is not so bounded, so the dynamics is not linear. The second right-hand term (in red) allows low-frequency shear to be concentrated by strain rate as shown in e). As two nearby isopycnals come together, the shear between them is increased. This model is combined with a computed vertical mode structure, the measured low frequency shear and the measured float depth time series to produce predictions of the strain rate and shear plotted as red lines in b) and c). The model predicts approximately the correct amplitude and phase for both shear and strain, indicating that the nonlinear straining of background shear and stratification is the dominant effect.

IMPACT/APPLICATIONS

Technically, the program has demonstrated the ability to operate Lagrangian floats for many months, controlled by two-way satellite communication and carrying a variety of multi-disciplinary sensors. With the higher bandwidth of *Iridium* satellites now available, such floats will be able to measure a wide range of environmental parameters and transmit them to shore in nearly real time. The recent development of the ability to air-deploy these floats will allow rapid worldwide deployment of these measurement capabilities.

TRANSITIONS

None

RELATED PROJECTS

These floats are nearly identical to those currently being used in the CBLAST study of air-sea interaction in hurricanes. These measurements acted as a proving ground for some of the CBLAST sensors.

PUBLICATIONS

D'Asaro, Eric A. 2003: **Performance of Autonomous Lagrangian Floats.** *Journal of Atmospheric and Oceanic Technology* : Vol. 20, No. 6, pp. 896–911